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Synopsis of **Ph.D. Thesis**

on

Geospatial Technologies for Hydrogeological Investigation of the Geba River Basin, Tigray, Ethiopia: Implications for Climate Change

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Chapter 1: Introduction

1.1 General introduction

Surface water and groundwater are the two most important components of the Earth's water supply and water cycle, playing critical roles in ecosystem sustainability and meeting the human's water demands. Surface water encompasses bodies of water that are accessible on the Earth's surface. Groundwater, on the other hand, is the hidden portion of water that exists beneath the earth's surface, particularly beneath the water table (Mallick et al. 2015). The pores in rocks, sediments, and soils are ideal for retaining water in its saturated state (Heath, 1998; Kidanewold et al., 2014). According to studies, the total amount of water contained in the Earth's hydrosphere is around 1386 million km^3 (Shiklomanov, 1998). Out of this total, 1351 million km^3 (97.5%) is concentrated in the oceans as salt water, while the remaining 35 million Km^3 (2.5%) is fresh water contributed by the land mass (Gleick, 1993). About three-fourths of total fresh water comes from glaciers and ice caps, with the remaining one-fourth coming from other portions of the land mass, 98% of which is stored underground (Hiscock, Kevin M and Bense, 2014).

Groundwater supplies 34% of total annual fresh water supply worldwide (Shekhar and Pandey, 2015). This supply is used by almost 2 billion people for a wide range of purposes (Kemper, 2004). The majority (65%) is used for irrigation, 25% for drinking, and the remaining 10% for industry (Hiscock, Kevin M and Bense, 2014). The rapid growth of the world's population, along with increasing irrigation and other agricultural practices, has resulted in a threefold increase in ground water obstruction over the past forty years (World Bank 2007). This issue is most apparent in the world's arid and semi-arid regions, where the trend of total ground depletion has more than doubled in the last forty years (Wada et al., 2010).

Ethiopia possesses 12 large drainage basins with a total annual water potential of 125.60 billion m^3, of which 123 billion m^3 (98%) comes from the surface and the remaining 2.6 billion m^3 (2%) is stored underground (Minstry of Water Resources, 2008). Because of the country's high topographic elevation, majority of surface water is lost as surface runoff to downstream countries. 86% of the Nile River Basin's volume of water, for example, is drained from the Ethiopian high lands (Gebreyohannes et al., 2013). For this reason, Ethiopia is recognized as Africa's water tower (Arsano and Tamrat, 2005). Despite the abundance of surface and

groundwater resources in the country, 66% of the population lacks access to safe drinking water (Internatioal Atomic Energy Agency (IAEA), 2013).

The northern part of Ethiopia, where the Geba river basin is situated, is characterized by a semi-arid climate and is fragile. Its fragile nature coupled with steep slopes, intense seasonal rainfall, and high population and livestock densities is the potential cause for huge soil erosion and land degradation (Zenebe et al. 2008). The basin is an area of high socio-economic importance but highly affected by water stress, recurrent drought, flooding, and erosion. Only few researches are undertaken in the drainage basin related to the drainage morphometry and groundwater recharge modelling

Fenta et al (2017) analyzed the quantitative morphometry of the Agulae watershed (Northeastern part of the Geba River Basin) using remote sensing and GIS techniques. The analysis revealed that the watershed is characterized mainly by the dendritic type of drainage pattern, elongated shape, fine drainage density, and high relief. Applying the same technique, Gebre et al (2015) undertook an analysis on Chelekot micro-shed attributes (Southeastern part of the Geba drainage basin). Dendritic type of drainage pattern, texture homogeneity, less elongated shape, medium drainage density, and moderate relief were found as the watershed characteristics. Gebreyohannes et al. (2013) Assessed the surface and the ground water of the Bain using spatially distributed water balance model, and concluded that majority of the precipitation is lost through evapotranspiration. Gebreyohannes et al. (2017) modeled the ground water flow using the MODFLOW modelling approach. The hydrological response of the upper Geba to the land use and climate change was modelled by Ashenafi (2014) using the Soil and Water Assessment Tool (SWAT) model, and accordingly, about 61% of the precipitation in the basin is lost through evapotranspiration, 18% becomes surface runoff, and 8% is recharging the deep aquifer.

Nevertheless, a comprehensive examination of hydrogeomorphic analysis, delineation of groundwater potential zones, hydrological modelling, and impact assessment of climate change on the basin's hydrology have not yet been undertaken. These analyses are essential for prioritising areas for soil and water conservation, conducting site-specific investigations, understanding the spatial distribution of hydrological components, and planning effective adaptation and mitigation strategies. Hence, this study is intended to address some of these aspects.

1.2 Review of related literature

In this study, aspects related to the objectives of the study have been reviewed from different literatures. These include, concepts related to hydrogeomorphic analysis, application of remote sensing and GIS in hydrogeomorphic analysis, GIS -based weighted sum approach for area priorities, application of remote sensing and GIS for groundwater potential zonation, GIS-based analytic hierarchy process for groundwater potential zonation, hydrological models, the Soil and Water Assessment Tool (SWAT), Climate change: Historical and future trends, impact of climate change on water resources, Climate models , Climate change Scenarios, and Shared socio-economic path ways (SSP) have been discussed in detail.

1.3 Study area description

The study was undertaken on the Geba river basin in northern Ethiopia. It is the main tributary of the Tekeze River basin, which is situated in the upper part of the Nile River basin. It lies at a latitude of $12^0$55'00" to $14^0$10'00" north and a longitude of $38^0$45'00" to $39^0$35'00" east on the geographic grid system (Fig.1). It originates at an elevation of 3300 meters (Mugulat Mountain) and runs 240 kilometres south-west till it reaches the mouth (Tekeze main Stream) at an elevation of 926 meters above mean sea level. The basin covers a total drainage area of 5137 Km^2, majority of which is accumulated at elevations ranging from 2300 to 2500 m.

The drainage basin is in a mountainous area with a tropical climate. Only three months (mid-June to mid-September) are considered as rainy seasons, while the rest of the months have prolonged dry weather. Based on data from meteorological stations inside and near the drainage basin for the past 13 years (2006-2018), the annual rainfall ranges from 450 mm to 950 mm, with a mean of 624 mm. The average temperature varies from 7 to 32 degrees Celsius.

The drainage basin's geological layers include Mesozoic sediments, pre-Cambrian rocks, tertiary volcanic rocks, and Palaeozoic sediments (Gebreyohannes et al., 2013). The soil types stratified in the drainage basin are Orthic acrisols, Dystric cambisols, Eutric cambisols, Humic cambisols, Eutric nitosols, and cambic arenosols. The major land cover/use classes detected by satellite image analysis for the year 2018 comprise agricultural land, bare land, brush land, forests, settlements, and water bodies. According to hydrogeological studies, major aquifers are not prevalent in the area, and aquitards are used for water extraction instead (Tesfamichael, 2009).

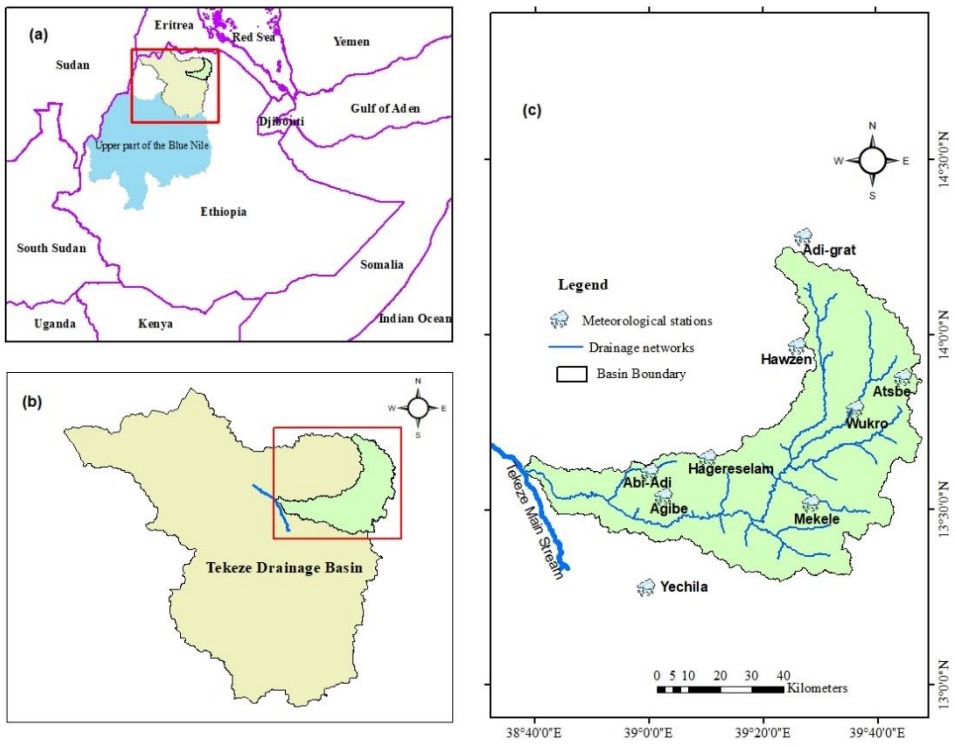

Fig.1 (a) location of Tekeze Drainage basin in Ethiopia (b) location of Geba River basin in Tekeze Drainage Basin (c) major Drainage networks and Meteorological stations in Geba Drainage Basin

1.4 Objectives of the study

Based on the detailed review of different aspects connected to the main work of the thesis, this study mainly focuses on hydrogeological investigation of Geba basin using geospatial technologies. To fulfill the main theme of the study, the main objectives of the study are to:

1 characterize the hydrogeomorphology of the Geba basin and prioritize areas for soil and water conservation measures using GIS-based weighted sum approach,

2 delineate the groundwater potential zones of the Geba basin using remote sensing data and GIS-based analytical hierarchy process,

3 model the hydrological components of the Geba basin using the soil and water assessment tool (SWAT) hydrological model, and

4 assess the impact of climate change on Geba basin's hydrology under changing future climate scenarios.

1.5 Outline of the thesis

The thesis is organized in to four chapters. The first chapter is the introduction part in which the general introduction of the study, literature review, study area description, and the objectives of the study are highlighted. The second chapter focuses on the data sources and methods employed to the four main objectives of the study, namely hydrogeomorphic analysis, groundwater potential delineation (zonation), hydrological Modeling, and impact assessment of climate change on watershed's hydrology. The third chapter deals with results and discussions related to each of the objectives of the study. Summary and conclusion of the entire study is provided in the fourth chapter.

Chapter 2: Materials and Methods

2.1 Data and data sources

For hydrogeomorphic characterization and sub-watershed prioritization, SRTM-DEM with a spatial resolution of 30m was downloaded from http://earthexplorer.usgs.gov, a commonly open data source developed by the United States Geological Survey (USGS) to extract the drainage system and the geomorphic parameters. To update the raw DEM, a topographic map (1:50,000 scale) was collected from the Ethiopian Mapping Agency (EMA).

For the groundwater potential delineation, drainage density, geomorphology, slope, and elevation layers were extracted from 30m SRTM-DEM, currently accessible at http://earthexplorer.usgs.gov. The lineament density and land use land cover layers were generated using Landsat 8-OLI data obtained from http://earthexplorer.usgs.gov. The lithological layer was digitized from the geological map of Ethiopia (scale1:2,000,000) developed by the Geological Survey of Ethiopia (EGS, 1972). The soil layer was downloaded from 1:5,000,000 scale digital soil map of the world developed by the Food and Agricultural Organization (FAO), currently available at https://data.apps.fao.org. Long term annual rainfall data (2006-2018) was collected from the Ethiopian Meteorological Agency (EMA). Groundwater yield data of boreholes (2017-2018) used for model validation were obtained from Tigray Region Water bureau and the Relief Society of Tigray

For hydrological modeling the data inputs were obtained from different sources. The slope was extracted from a spatial resolution of 12.5m PALSAR- DEM obtained from Alaskan Satellite Facility (https://search.asf.alaska.edu). Lulc was extracted from a 30m land-sat

image accessible at http://earthexplorer.usgs.gov, the soil layer was obtained from FAO portal (https://data.apps.fao.org). The metrological parameters (precipitation, maximum temperature, minimum temperature) of 30 years (1984-2014) of four metrological stations was collected from the Ethiopian Metrological Agency. The stream flow (1992-2003) used to validate the performance of the SWAT model was obtained from The Ministry of Water, Irrigation, and Electricity of Ethiopia

For climate change projection, observed data (1985-2014) of four metrological stations was collected from the Ethiopian Metrological Agency, while both the historical (1985-2014) and projected data (2014-2100) of five GCMs (CanESM5, MIROC6, NorESM2-MM, MPI-ESM1-2-LR, -GFDL-ESM4) and three Shared Socio-economic pathways (SSP126, SSP245, SSP458) were obtained from https:// esgf-node.llnl.gov/search/CMIP6/.

2.2 Methodology

2.2.1 Hydrogeomorphic characterization

Hydrogeomorphic characterization and ranking of watersheds according to their susceptibility to soil erosion is crucial in setting priorities for soil and water conservation initiatives. The main intention of this work is to characterize and prioritize 12-sub-watersheds of the Geba River Basin northern Ethiopia for planned soil and water conservation practices. SRTM-DEM, GIS, and statistical correlation-based weighted sum approach have been utilized for generating geomorphic parameters, data processing, and calculating the combined rank of sub-watersheds respectively. Fourteen geomorphic parameters that have high nexus with the soil erosion susceptibility were selected and quantified using different standardized mathematical equations. Based on these quantified variables, a compound factor (rank) was calculated for each sub-watershed. Using the combined rank, the sub-watersheds were clustered into five soil erosion susceptibility zones, i.e., very high, high, moderate, low, and very low.

2.2.2 Groundwater potential zonation

Geospatial technologies and multi-criteria decision-making techniques have recently emerged as effective approaches for assessing groundwater potential, particularly in areas where ground data is scarce. The objective of this study is to identify the groundwater potential zones of Northern Ethiopia's Geba Drainage Basin. Nine groundwater indicators were used as inputs, including lithology, geomorphology, lineament density, drainage density, slope, elevation, land use and land cover, rainfall, and soil. Based on their relative influence on the groundwater potentiality, all the inputs and their classes were assigned weights. The assigned weights were then normalized using the Eigen vector-based Analytical Hierarchy Process. With the aid of ArcGIS software, the normalized inputs and their classes were superimposed to generate the groundwater potential map. The generated groundwater potential was then delineated in to five distinct groundwater potential zones.

2.2.3 Hydrological modelling

Hydrological parameters are important inputs for watershed management. The intention of this study is to simulate the hydrological parameters using the Soil and Water Assessment Tools (SWAT) model. To achieve this objective, the entire drainage basin was segmented in to 39 sub-catchments and 516 Hydraulic Response Units (HRUs). The simulation was performed for 31 years (1984-2014) of meteorological data. Sensitivity analysis, calibration, and validation of the model was performed by sequential uncertainty fitting-2 (SUFI) of the SWAT Calibration and Uncertainty Programmes (SWAT_CUP). 8 years (1992-1999) and 4 years (2000-2003) of measured stream flow data were used for calibration and validation of the model. To evaluate the performance of the model, the coefficient of determination (R^2), Nash-Sutcliffe (NSE), and percent bias (PBIAS) have been employed.

2.2.4 Impact assessment of climate change on watershed hydrology

Prediction of the impact of the climate change on the hydrological parameters is of high crucial for proactive planning and management of water resources, particularly in semi-arid regions. To predict the hydrological changes under the future climate change scenarios, the SWAT model has been utilized. The climate change was assessed based on average ensemble of five CMIP6 General Circulation Models (GCMs), namely CanESM5, MIROC6, NorESM2-MM, MPI-ESM1-2-LR, and -GFDL-ESM4 and three Shared Socio-economic pathways (SSP126, SSP245, SSP458). To assess the climate change of the future scenarios, two future

time frames were considered: The near future (2021-2050) and the far future (2071-2100). The changes in climate and hydrological parameters were compared against the values of the historical period (1985-2014).

Chapter 3: Results and discussion

3.1 Hydrogeomorphic characterization

Results revealed that sub-watersheds 7, 8, 9, and 12 which collectively cover most of the area (36 % of the total area) are possibly fall under the very high soil erosion susceptibility. The high (comprising of sub-watersheds 1, 5, 11), moderate (consisting of sub-watersheds 2, 3), low (consisting of sub-watershed 10), and very low (consisting of sub-watersheds 4, 6) soil erosion susceptibility zones cover 26%, 28%, 4%, and 6% of the total area respectively.

The current study's total area covered by the very high soil erosion susceptibility zone (36%) was compared to similar studies conducted in different regions. Malik et al. (2019) reported 20% area coverage by very high soil erosion susceptible zones, whereas (Aher et al. 2014) reported 31% coverage. In comparison to the other results, the high value of soil erosion susceptibility in the Geba drainage basin indicates a high level of soil erosion risk and the need for immediate action.

Nine of the 12 sub watersheds (75% of the sub watersheds) in the Geba drainage basin were found to have medium to very high soil erosion susceptibility. This is somewhat nearest to the findings of Jothimani et al. (2020), a study carried out in southern Ethiopia, where 65% of the sub-watersheds were found to have moderate to very high soil erosion status, but it differs greatly from the findings of (WSA-1) a study conducted in India's semi-arid tropics where 20% of the sub watersheds have moderate to very high soil erosion status. This variation may be attributed to topographic differences between sub-watersheds.

3.2 Groundwater potential zonation

Five distinct groundwater potential zones—very good, good, moderate, poor, and very poor were found in the study area. The areal distribution showed that majority of the area (45%) fell within the poor groundwater potential zone. The groundwater potential zones of moderate, very poor, good, and very good cover approximately 27%, 12%, 10%, and 6% of the total area,

respectively. The results were compared to the groundwater yield of boreholes collected from the study area. The validation analysis revealed a 72% similarity, which is representative

This result is consistent to the findings of previous similar studies conducted in various semi-arid regions. For instance, (Abdulkerim et al., 2022) reported 72% agreement between actual data and GIS-derived groundwater recharge potential zones in Sude district, southern Ethiopia. Similarly, (Das et al, 2019) approved 71.43% similarity in predicting groundwater potential zones in the Puruliya district of West Bengal (India)

The very good GWPZs, in the south-west and north of the drainage basin, cover 301 km^2 (6% of the total area) are attributed to Jurassic sandstones, Cambic arenosols, hill land forms, and flat slopes. Good GWPZs, mainly in the central, south-west, and northern portions of the drainage basin, cover 529 km^2 (10% of the total area). This zone is constituted by low drainage density, Jurassic sandstones, high lineament densities, low mountain land form, and moderately steep slopes. Moderate GWPZs which encompass 27% (1394 km^2) of the total area and located in most portions of the drainage basin, are underlined by cretaceous sandstones, Eutric nitosols, low mountains, and agricultural land classes. The poor GWPZs (mainly concentrated at the central portion of the drainage basin) constitute 45% (2288 km^2) of the total area, are characterized by lime stone-shale-marl, Eutric nitosols, moderately steep slopes, and bare land classes. The very poor GWPZs, situated in the west and north-east of the drainage basin, cover 612 km^2 (12% of the total area) and are dominated by volcanic and basement rocks, Eutric nitosols, high drainage density, low land forms, and moderately steep slopes.

The layer wise distribution of the GWPZs agrees with the findings of earlier investigations. (Manap et al., 2013), determined high groundwater potential zones with flat slope, low drainage density, and high lineament density. (Rahmati et al., 2015), on the other hand, identified low groundwater potential zones in areas with steep terrain, high drainage density, and impermeable lithology. Furthermore, (Pande et al., 2018) reported that locations with unconsolidated sediments such as gravel, sand, silt, and clay possess high groundwater potential zones.

3.3 Hydrological modelling

Outputs of the model affirm that annual evapotranspiration ranges from 271 to 374 mm/year with a mean value of 323 mm/year, majority of which is occurred in the summer season. Areas with lower values of evapotranspiration are in the southern and northern portion and those of

with higher values are in the north eastern and south western portion of the basin. Precipitation and soil types to some extents are responsible for the annual variation of evapotranspiration Annual surface runoff ranges from 34 to 175 mm/year with a mean value of 94 mm/year, majority of which is attributed to the summer season.

3.4 Impact assessment of climate change on watershed hydrology

The impact assessment was based on the average ensemble of five Coupled Model Intercomparison Project Phase 6-General Circulation Models (CMIP6-GCMs; CanESM5, MIROC6, NorESM2-MM, MPI-ESM1-2-LR, GFDL ESM4), in conjunction with three shared socio-economic pathways (SSP), low (SSP126), medium (SSP245), and high (SSP585) emission scenarios over two future time ranges, namely the near time range (2021-2050) and far time range (2071-2100). Biases associated to the GCMs were corrected using the quantile mapping (QM) approach. Results show that the bias corrected historical average ensemble of the GCMs closely fit with the observed records at (R2=0.93, RMSE=1.53, MAE=1.28), (R2=0.89, RMSE=1.04, MAE= 0.84), and (R2=0.77, RMSE=2.35, MAE=1.11) for maximum temperature, minimum temperature, and precipitation respectively. Despite differences, all the climatic and hydrological parameters show substantial projected increases across all adopted SSPs. Annual minimum (maximum) temperature is projected to increase by 0.72 to 0.83 0C (1.07 to 5.4 0C) over the future periods under all three scenarios. Annual Precipitation over 2021-2050 (2071-2100) is expected to increase by 22-34 % (19-54%) under all three scenarios. The highest likely percentage changes in annual evapotranspiration, surface runoff, baseflow, and streamflow reaches up to +33%, +46%, + 47%, and +41% respectively over the far time range (2071-2100) under SSP585. The high projected increases in surface runoff and river flow, particularly in the far time range would imply a higher possibility of flash floods, a destructive consequence for the wellbeing of the community, requiring a proactive adaptation and mitigation measures.

Chapter 4: Summary and conclusions

A comprehensive geospatial hydrogeological investigation with emphasis on the hydrogeomorphic analysis, groundwater potential zonation, hydrological modeling, and impact assessment of climate change on the hydrology of Geba River Basin, Tigray, Ethiopia are summarized along with the following conclusions.

The hydrogeomorphic analysis of the study area helped to characterize and prioritize sub-watersheds to properly plan and implement soil and water conservation methods. The focus was on 12 sub-watersheds of the Geba river basin. To achieve this goal, STRM-DEM, GIS, and statistical correlations-based-weighted sum approaches have been integrated.

Hydrogeomorphic parameters which are more sensitive to soil erosion were selected as input variables for ranking the sub-watersheds. Using the input variables, compound factor (rank) was computed for different sub-watersheds. Based on the compound factor values, five distinct soil erosion susceptibility zones have been identified. These include, very high, high, moderate, low, and very low covering an area of 1860 km^2 (36 %), 1358 km^2 (26 %), 1426 km^2 (28 %), 185 km^2 (4 %), and 308 km^2 (6 %) respectively. Four sub- watersheds, namely SW-7, SW-8, SW-9 and SW-12 exhibit very high erosion susceptibility zone, three sub-watersheds including SW-1, SW-5 and SW-11 cover the high erosion susceptibility zone, the moderate soil erosion susceptibility zone contains two sub-watersheds (SW-2 and SW-3), the low soil erosion susceptibility comprises only one watershed (SW-10), and the very low soil erosion susceptibility zone has two sub-watersheds (SW-4 and SW-6).

The results warn for an immediate action plan to be implemented to avoid the very high rates of erosion sites. This must be followed by second action at high erosion susceptible sub-watersheds, and so on until sufficient time and resources are available to reach the remaining sub-watersheds. Plantation practices and construction of artificial recharge structures, such as, check dams and contour trenches are some of the examples for mitigative measures to reduce surface runoff, thereby increasing the infiltration capacity.

The study area is poorly gauged and data available related to this study are scarce. It is also inaccessible for field-based investigations, including funding resource, and skilled manpower. As a result, the findings of this study could be used as an alternative option not only to reduce soil erosion, but also to select reliable artificial recharge sites for the exploration of groundwater.

The groundwater potential zonation techniques have been used to understand the trend of water resources which is reliable and efficient for small-scale studies. However, these methods are not feasible to apply on a large scale and are not able to reach remote and inaccessible locations. Such uncertainties have been solved with the advent of geospatial technologies for example, remote sensing and GIS. The potential effectiveness of these methods has been confirmed in many parts of the world, but they have yet to be tested in areas where infrastructure is limited.

One purpose of the present study was to delineate the groundwater potential zones of the Geba drainage basin in northern Ethiopia, where water-stress and food insecurity are quite severe. This was accomplished using weighted linear combination (WLC) of various groundwater indicators, such as lithology, geomorphology, lineament density, drainage density, slope, elevation, rainfall, soil, and land use/cover. Remote sensing technology was used as a data source, an analytic hierarchy process (AHP) to normalize the judgment scales, and GIS was used as a platform to generate the ground water potential map.

Five distinct groundwater potential zones were identified in the study. These can be classified as, very good, good, moderate, poor, and very poor, each covering an area of 301 km^2, 529 km^2, 1394 km^2, 2288 km^2, and 625 km^2, respectively. The combined effects of Jurassic sand stones, loamy sand soils, flat slopes, low drainage densities, and high lineament densities are found to be promising for the development of good and very good groundwater potential zones. The presence of basement rocks, sandy clay loam soils, steep slopes, bare land classes, and high drainage densities are accountable for the poor and very poor ground water potential zones.

The groundwater potential map generated by using the current methodology has been validated using the borehole yield data and showed 72% similarity, which is in the acceptable level of reliability. The adoption and implementation of remote sensing and GIS-based analytical hierarchy process is, therefore, found to be the alternative option for delineating the groundwater potential zones of the Geba river basin.

The outcome of these techniques are qualitative judgments that only determine the likelihood of groundwater occurrence and its spatial distribution. It can, however, provide preliminary information for site-specific investigations and site selection, thereby saving time and money. The developed groundwater potential map, is therefore, recommended for use by

water public bodies, planners, and decision makers as a base for groundwater resource management.

Hydrological modelling of the Geba basin has been performed using the SWAT hydrological model. The DEM-generated slope, FAO-generated soil type, and Landsat-generated land use/land cover, and meteorological records were used as data inputs. The Output of the model affirm that annual evapotranspiration ranges from 271 to 374 mm/year with a mean value of 323 mm/year, majority of this occurs during the summer season. Areas with lower values of evapotranspiration are in the southern and northern portions and those of with higher values are in the north eastern and south western portions of the basin. Precipitation and soil types to some extents are responsible for the annual variations of the evapotranspiration.

Annual surface runoff ranges from 34 to 175 mm/year with a mean value of 94 mm/year, majority of which is attributed to the summer season. Areas with lower values of surface runoff are in the south eastern part as compared higher values in the southwestern and north eastern portions of the basin. Areas of the basin with high surface runoff are underlined by bare land and agricultural land cover/land use and sandy clay soils.

The results of this study also underscore that using the SWAT model for watersheds which been found to be feasible as evidenced from the positive correlation between the simulated and observed flows recommending to apply for other similar cases.

The impact assessment of climate change on watershed hydrology has been studied by using geospatial technologies. Like any resources, the availability and accessibility of water is affected by climate change and its variability. The impact becomes worst in regions like east Africa, particularly the Geba river. The response of watershed hydrology to climate change has been assessed by using semi-distributed and physically -based SWAT hydrological model. Ensemble average of five GCMs associated with the three emission scenarios, SSP126, SSP245, and SSP585 from CMIP6 were utilized for predicting changes during 2021-2050 and 2071-2100. A quantile mapping technique was adopted for bias correction of daily temperature and precipitation by transforming the quantiles of the observed data in to the model output counterpart.

The bias corrected for daily maximum temperature, minimum temperature, and precipitation data were fed into the SWAT hydrological model to simulate the hydrological components affected by the climate change, including evapotranspiration, surface runoff, baseflow, and streamflow. Maximum and minimum temperatures were consistently shown

projected increases in both future time terms and all SSP scenarios compared to the baseline, with the highest values under SSP585 over the far time range. Precipitation has also shown to be consistently projected mean annual increments in both future time scales across all the SSP scenarios, with larger values in the far time range than the near time range in all the SSP scenarios, particularly under SSP585.

Evapotranspiration projected to increase in the annual scale over future time scale, with lowest under SSP126 over the near time range and the highest under SSP585 over the far time range. Declined trend in evapotranspiration was noticed in the wet-season with all SSP scenarios over both future time ranges, except in SSP245 over the near time range and SSP585 over the far time range. Surface runoff has exhibited the increase in the annual scale in all SSP scenarios over both time ranges, with peak over the far time range under SSP585, but experience projected decreases in the seasonal scale, particularly during the dry-season over all future time ranges and SSP scenarios. Baseflow and streamflow are expected to increase at both annual and seasonal scales, over the near time range under SSP126 and far time range under SSP585 respectively.

The projected changes in evapotranspiration rates are mainly determined by the variations in projected temperature, while changes in runoff, baseflow, and streamflow are mainly controlled by variations in the precipitation. The projected increase in the surface runoff and river flow, particularly in the far time range will result in the vulnerability of the natural watershed to frequent flash floods, bringing a deleterious consequence for the general public. Increased runoff in the watershed may be favourable for water management practices such as irrigation and hydroelectric power generation. However, the decline of runoff and river flow, particularly the dry - season may amplify shortage of water resources.

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